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DATA ACQUISITION FOR MAGNETIC RESONANCE IMAGING TECHNIQUE

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a method of data acquisition for a magnetic resonance imaging (MRI) technique, and more particularly, to a method of data acquisition for taking multiple images in sequence with a single contrast injection. According to the present invention, the multiple images can be taken with multi-orientation overlapping thin slabs, or the images can be individually taken as the patient is moved rapidly between different positions during the data acquisition period.

BACKGROUND AND SUMMARY OF THE INVENTION

Magnetic Resonance Imaging techniques for performing three-dimensional Magnetic Resonance Angiography (3D-MRA) are traditionally performed by placing the receiving antenna, or slab, over the relevant portion of the body, injecting the patient with a suitable dye and then triggering the M.R.I. data acquisition process while the patient holds his or her breath. Holding the breath is important to ensure that the arteries being examined do not move during data acquisition due to the expansion and contraction of the lungs and diaphragm. In conventional practice, the data are acquired during the arterial phase (before the dye is pumped by the heart into the venous system). Because the injected dye tends to dissipate quickly, in the arterial system, and is ultimately pumped into the venous system, data must be taken comparatively quickly. Thus, using conventional techniques, it has not been possible to image different regions of the body from a single dye injection. The time required to position the patient and imaging slab is too long and the injected dye will have dissipated before the next view can be set up and acquired.

When multiple regions must be imaged with a single dye injection, the conventional approach has been to use multiple coils positioned in advance over the regions of

interest. The data acquisition system is then programmed to collect data from the multiple coils in sequence. However, during the entire multiple slab acquisition sequence, the patient must remain very still and hold his or her breath. Unfortunately, for some tests, and for some critically ill patients, it is simply not possible to hold the breath throughout the entire sequence. (The data acquisition sequence for a single view can take approximately one to two minutes, depending on the data array size.)

The conventional data acquisition sequence involves the collecting of data for a single view and then processing that data to form an image suitable for display on screen or printout. A single view will typically comprise a plurality of partitions, with each partition comprising a plurality of lines. Typically, when imaging the chest, the partitions are acquired by electro cardiographic (E.C.G.) triggering at the R-wave. Thus, the number of partitions in a single view will correspond to the number of heartbeats. Within each heartbeat interval (R-R interval), a plurality of lines of data is acquired on the order of about ninety-six (96) lines. The number of lines acquired will depend on the patient's R-R interval and the time it takes to complete a single line of data acquisition.

In order to interpret the data meaningfully, certain parameters are set into the M.R.I. system. These parameters quantify such physical properties as the orientation of the coil, the pixel size, and the thickness of the slab or portion of the body to be imaged. The M.R.I. system uses these parameters to interpret the raw data from the receiving antenna coil, so that the data may be processed in a unified way by the imaging software. A typical view or slab might comprise twenty (20) to thirty (30) partitions, each being approximately two to three millimeters in thickness. In practice, a larger number of partitions cannot be completed in a reasonable, single

breath-hold period. However, with newer techniques, such as SYNC interpolation of data in the Fourier domain, the partitions can be doubled without increasing scan time.

After acquisition of the raw data, as described above, the M.R.I. system automatically converts this data into image data, using imaging software that is resident in the M.R.I. system. Image processing is very data intensive, accounting for a substantial portion of the overall data acquisition cycle. As noted above, the entire data acquisition cycle, including this processing of raw data, can take one to two minutes to complete. During this time, the injected dye will have dissipated or moved into the venous system, making subsequent views impractical from a single dye injection.

The present invention solves the aforementioned problems by altering the data acquisition cycle so that multiple views (in multiple orientations) can be taken. This is accomplished by delaying image processing until raw data from all views have been collected, and by programmatically inserting a predetermined dead time between views during which time the patient is permitted to exhale and inhale. The improved data acquisition system also automatically changes applicable parameters on the fly, to accommodate different orientations between views, or to alter other parameters as may be needed to obtain the most useful images. The ability to perform a sequence of views without the need for technician interaction between views is of considerable benefit in acquiring data from multiple slabs automatically. However, the improved data acquisition system does far more than this. In one embodiment, the data acquisition can supply position data to a moving table, allowing the patient to be automatically moved to different positions within the M.R.I. device. Accordingly, the patient can be moved using a kinematic examination table so that different body portions such as the chest, abdomen, and legs can be imaged in sequence with a single contrast injection.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood, however, that the detailed description and specific examples, while indicating preferred embodiments of the invention, are intended for purposes of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

Figure 1 shows an example of the data acquisition stages, where three views are sequentially acquired at three different orientations;

Figure 2 illustrates diagrammatically how individual views are in turn subdivided into partitions, which are in turn subdivided into lines, a delay period is executed between each view;

Figures 3 and 4 give further details on how the views are subdivided into partitions (Fig. 4) and the partitions are subdivided into lines (Fig. 3);

Figure 5 shows how the software system of the improved data acquisition invention may be implemented; and

Figure 6 shows a data flow diagram for the control software according to the principles of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows an example of the data acquisition system, where three views are sequentially acquired at three different orientations. Note that between each view is a dead time that is generated by the software of the invention. As illustrated, each view involves a number of physical parameter settings that the system uses in interpreting the raw data. As will be explained, the data acquisition system will automatically change parameters to

match the physical attributes of each given view or orientation. The different orientations can include taking an image of, for example, a vertical slab or slice of a patient's chest, and then taking images at a different orientation such as a horizontal slab or slice of the same area giving an orientational view which is different than the first image. Most importantly, according to the present invention, a delay period is provided between the first imaging sequence and the second image sequence in order to allow the patient to exhale and inhale prior to again holding his breath for the second image to be taken. In addition, the patient can be moved on a kinematic imaging table during the delay period so that different portions of the patient's body can be imaged in sequence using a single injection of contrast material as the contrast material travels through the vascular system to the different portions of the patient's body. The system of the present invention thus permits a dynamic contrast-enhanced breath-hold magnetic resonance angiography technique using a multi-orientation and multiple overlapping slab acquisition (MO-MOTSA), as well as an MRA technique which allows multiple body portions to be scanned in sequence using a single contrast injection.

Figure 2 illustrates diagrammatically how individual views are in turn subdivided into partitions, which are in turn subdivided into lines. Note that after all partitions of a given view have been acquired, the system will automatically set a predetermined delay before the partitions for the next view are acquired. Figures 3 and 4 give further details on how the views are subdivided into partitions (Fig. 4) and partitions are subdivided into lines (Fig. 3). The manner in which views are subdivided into partitions and lines are generally known in the art.

Figure 5 shows how the software system of the improved data acquisition invention may be implemented. Although there are a number of different ways to achieve the data acquisition sequence, the illustrated embodiment uses a

conditional branching loop to cycle through the plurality of views, selecting parameters from a parameter table. In Figure 5, the parameter table is shown diagrammatically at 100. In the illustrated example, there are four parameters (a, b, c, d) for each of three views (1, 2, 3). The parameters may be supplied by user input through a suitable interface 102. If desired, multiple parameter tables can be stored in the system and used as templates for performing different types of M.R.I. techniques. The user would then select the appropriate template corresponding to the type of procedure being performed, and would then enter into the template the desired parameters corresponding to the patient's physical characteristics or to the radiologist's instructions.

The software routine begins at Step 110 by pointing to the head of the parameter table. As will be described, the pointer is used to determine what parameters are loaded from the table. The pointer is indexed to the next set of parameters in the table for each of the views to be performed.

After initializing to the head of the parameter table, the routine, in Step 112, loads the parameters from the table into the system for execution. Then, in Step 114, after the patient has been injected with a suitable contrast material and the material has traveled through the arterial system to the body portion being viewed, the scan for the current view is run. This will involve acquiring all lines of data for all partitions that comprise the current view. See Figures 2-4 for details. After the scan for the current view is complete, the system then executes a dead time routine at 116. Preferably, the dead time interval can be a predetermined value supplied by the user through user interface 102. Although the current system uses the same dead time value between all views, the system can be readily adapted to execute different dead times between views, as may be desired in a particular procedure. Typically, the dead time will correspond to the amount of

time it takes for a patient to exhale and inhale and again hold his or her breath for the next view to be taken at a different orientation. When the patient is being moved so that a different body portion (such as moving from the abdomen to the legs) is being imaged, the dead time can correspond to the time it takes for the contrast material to travel from the first body portion being viewed to a second body portion to be viewed.

It will be recalled that during the dead time the patient is permitted to exhale and inhale. If desired, the system can be programmed to issue a prompt at Step 118 to notify the attending technician or patient that the patient may exhale and inhale. A suitable audible or visual prompt can be generated for this purpose. Also, if the system is configured to perform automatic patient repositioning, such as on a kinematic table, the appropriate motor control signals are generated to move the table on which the patient is resting at Step 120. The step of moving the patient can also be performed manually by a technician.

After the dead time is complete, the program tests at conditional branching operation 122 whether the final scan specified in the parameter table has been completed. If not, control branches to Step 124, where the parameter table pointer is indexed to the next entry in the table, and the program branches back to Step 112. At this time, additional images are obtained in sequence until the desired orientations and/or the desired portions of the body are imaged in series. If the final scan has been completed at Step 122, then control branches to Step 126, where the image data for all views are then processed.

Figure 6 illustrates a data flow diagram for the control system software according to the principles of the present invention. Existing MRI systems include a data collect module 200 which loads the parameters for a scan sequence and collects the image data during the scan process. The MRI systems also include an imaging processing module 202 which receives the image data from

the data collect module 200 and processes the images and displays them either on computer screen or in hard copy form as represented by reference numeral 204. Existing MRI systems also include means for entering and storing the parameters 206 for a scan sequence, as well as storage means 208 for storing the image data collected by the data collect module 200. The image processing module 202 receives the image data from the data storage 208. Typically, MRI systems are utilized for a single scan sequence and the data collected by the data collect module 200 is immediately processed by the image processing module 202 upon completion of the scan sequence. Existing MRI systems are not provided with software for carrying out a plurality of scan sequences using different sets of parameters which are separated by a delay period and storing the image data corresponding to each scan sequence in designated locations so that the image processing module can, upon completion of the scan sequences, process the image data for each of the scan sequences (views).

Accordingly, the present invention provides a controller 210 which initiates each scan sequence and has associated with it a parameters table manager 212 which manages the parameter sets, stored in the parameters table 206 which are input into the data collect module 200 corresponding to each scan sequence. The controller also has associated with it a data store manager 214 for managing the storage of image data corresponding to each scan sequence. The data store manager 214 tells the data collect module 200 where to store the image data which is collected by the data collect module 200 and stored in storage 208.

Controller 210 also has associated with it, a delay timer 216 which institutes a delay period between each scan sequence. The controller 210 initiates a first scan sequence by directing the parameters table manager 212 to input the appropriate parameters from parameter tables 206 into the data collect module 200. The controller also

directs the data storage manager 214 to instruct the data collect module 200 where to store the image data collected in the scan sequence. At the completion of a scan sequence, the controller initiates the delay timer 216 for instituting a delay period between each scan sequence. During the delay period, the patient is allowed to breathe prior to holding his or her breath again during a subsequent scan sequence at a different orientation. The patient can also be moved to a second location so that a second scan sequence can be performed on a second body portion. If an automatic table moving device is utilized, such as table motor 218, controller 210 can provide a signal to actuate the table motor 218 to move the patient to a second orientation for obtaining a scan sequence of a second body portion of the patient. A control interface 220 is provided for activating the image processing module 202 in response to a signal from the controller 210 after the data acquisition is complete. The software system of the present invention allows a method of data acquisition for taking multiple images in sequence with a single contrast injection wherein the images can be at different orientations (MO-MOTSA) or wherein the patient is moved rapidly between different positions during the data acquisition. In either case, a delay period is provided between each scan sequence to allow the patient to breathe and again hold his or her breath for a subsequent scan sequence.

Description of Clinical Examples

Three dimensional magnetic resonance angiography (3D-MRA) techniques have been routinely used in the past for vascular imaging. In particular, 3D-MRA in a single breath-hold [Simonetti OP, Finn JP, White RD, Bis KG, Shetty AN, et al. ECG-triggered breath-held gadolinium-enhanced 3D MRA of the thoracic vasculature(abstr). In: Book of abstract: International society of Magnetic Resonance in Medicine 1996:703. Shetty AN, Shirkhoda A, Bis KG, Alcantara A. Contrast enhanced three dimensional MR

angiography in a single breath hold: A novel technique. AJR 1995;165:1290-1292.] has been shown to be a very useful and rapid technique when used with paramagnetic contrast agents. Given the rapid nature of this new sequence, with the acquisition of an entire 3D-data set during the passage of MR contrast material through the arterial system, arterial phase imaging is possible. A delayed acquisition following the initial arterial phase results in the visualization of venous flow. Conventionally, a breath-hold 3D-MRA study is performed by placing a single slab (view) of a desired thickness whose orientation is set to cover most of the vessels in question. The number of partitions within the slab (view) and in-plane phase encoding steps are adjusted to complete the acquisition in a reasonable single breath-hold period which is anywhere from 15-25 seconds. The data processing takes anywhere from 20-40 seconds depending on the data array size. These techniques have been successfully used to obtain a dynamic measurement in a single orientation. [Maki JH, Prince MR, Londy F, Chenevert TL. The effect of time varying intravascular signal intensity and k-space acquisition order on 3D MR angiography image quality (abstr). In: Book of abstract: International Society of Magnetic Resonance in Medicine 1996:237. Debatin JF, Schmidt M., Gohde S., Hany T., Pfamatter T, Krestin GP., McKinnon GC. 3D breath hold MRA of the renal arteries under 30 seconds. (abstr). In: Book of abstract: International Society of Magnetic Resonance in Medicine 1996:165.] In many cases, multiple measurements are made in the same orientation to obtain arterial and venous phase information. However, to obtain additional images at a different orientation, the data acquisition is repeated by repositioning the slab (view) with a new orientation. A different orientation is frequently required to better portray the 3-dimensional aspects of complex vascular anatomy with high resolution. Since, the data acquisition of the newly positioned slab (view) can only commence after the previous image data

processing is completed, a wait of about 1-2 minutes between scans is elapsed during which most of the contrast bolus is washed out. A subsequent measurement will yield images with poor arterial and venous signal due to this prolonged delay. The present invention provides a method in which multiples slabs, either in the same or different orientation may be prescribed to acquire the arterial and venous phases with a single contrast injection.

Materials and methods:

All studies were performed using a 1.5 Tesla Magnetom Vision MR system (Siemens Medical Systems, Iselin, NJ). Thirty subjects with known aortic (10 thoracic, 1 abdominal, 1 arch vessel), pulmonary artery (6), or cardiac (7) disease and 5 volunteers were recruited with informed consent approved by the institutional review board of the hospital. Patients were positioned supine with a quadrature phased array body coil. A 20-gauge angio-cath needle was placed in an anticubittal vein and the other end of the line was connected to a contrast injector (Spectra II, MedRad, Pittsburgh, PA) which was used to infuse contrast at a rate of 2 or 3 cc /sec. Any 3D MRA or MRI pulse sequence can be used with this technique. We used an ECG triggered 3D FLASH (Fast Low Angle single Shot) pulse sequence. Each of the partitions along the slab (view) select direction was acquired by triggering at the R-wave. Thus, the number of partitions correspond to the number of heart beats. About 96 lines were acquired in a single R-R interval for each partition. The number of lines that were acquired depended on the patient's R-R interval and the time to complete a single line of data acquisition. The imaging parameters were TR/TE = 5.0/2.0, flip angle = 15 ^{0}, matrix = 96 x 256, partition thickness = 2 - 3 mm and the number of partitions were limited to 22-30 so that a single measurement could be completed in a reasonable single breath hold (after deep inspiration) period. It should be noted that the above sequence is just one sequence that was implemented. Other gradient echo, spin echo, or fast

(turbo) spin echo sequences can also be implemented using this concept.

The delay between successive slab measurements was fixed at eight seconds. During this period, patients were prepared to hold their breath for the next measurement. Prior to contrast injection, the sequence was applied once to obtain base-line images in the same three orientations which were then used for subtracting from the corresponding post-contrast images. Subtraction was used in only five patients where as in remaining patients source images resulting from contrast were used. Prohance (Gadoteridol) (Bracco Diagnostics, Princeton, NJ) at the dose of 0.2 mmol/kg was injected at the rate of 2 or 3 cc/sec using the injector followed by 15 cc of saline flush. The first measurement was obtained between 5-10 seconds (for pulmonary studies) or 10-15 seconds (for aortic studies) after the onset of contrast injection. Second and third measurements were subsequently obtained with a total time for all three measurements of 54 seconds.

Results:

All patients tolerated three successive measurements with breath-holding. All measurements revealed a moderate enhancement of the blood pool of the target area of interest. All 30 subjects underwent three measurements in which 26 were imaged in two different planes (one of the imaging planes was repeated) over time and four were imaged with three different planes over time. Among the 10 patients with thoracic aortic disease, the following abnormalities were imaged: Type A dissections (4), Type B dissections (2), aorto-annular ectasia (1), atherosclerotic aneurysms (2) and atherosclerotic narrowing (1). There were two normal thoracic aortas imaged. One plane of imaging is not optimum in dissection patients since the imaging plane may be parallel with the intimal flap which may go undetected. The three-dimensional relationships of thoracic aortic aneurysms was also better appreciated with the MO-MOTSA technique.

Among the pulmonary abnormalities, the following were imaged with MO-MOTSA: pulmonary artery aneurysm (1), lung carcinoma mimicking arteriovenous malformation on CT (1), infiltrate/atelectasis (2) and chronic pulmonary embolus (1).

There were seven patients with a variety of cardiac abnormalities that were imaged with MO-MOTSA and included the following: hydatid cyst of the interventricular septum (1), pericardial effusions (3), pericardial cyst (1), right atrial lipoma (1) and left ventricular aneurysm with thrombus (1). Thickening of the pericardium with pericardial effusions was better appreciated with the multi-planar aspects of MO-MOTSA imaging.

Discussion:

We have shown a new way of acquiring 3D-MRA images in multiple orientations. The technique can also be used in other parts of the body for depicting vascular and non-vascular anatomy. Typically, a 3D pulse sequence takes 15-18 seconds to complete 96 lines and 24 partitions. By running the pulse sequence repeatedly, arterial and delayed arterial and venous phase imaging is possible. It should be noted that other sequences can also be implemented. Most scanners provide a means to achieve this by increasing the number of measurements of the same slab orientation with an appropriate time delay between measurements. However, this restricts one to achieving vascular information along only one orientation. To render projections along the other directions, a multi-planar reformatting (MPR) of the data can be used before subjecting the data to maximum intensity projection (MIP), however, the spatial resolution is lost especially when the raw data voxels are non-isotropic. In addition, with MIP, due to pixel replication, the projections deviating significantly from the true acquisition plane have a significantly diminished resolution. The method described here allows for acquiring data in multiple orientations without a loss of vascular signal. This also allows for

MIP along those multi-planar directions without the loss of spatial resolution.

Using a variable delay between 3D slabs allowed for imaging of vascular territories in different orientations during the arterial peak of contrast enhancement. The method is very useful in obtaining high resolution images of the aorta and pulmonary vasculature and cardiac anatomy. This method may also prove useful in the future when the patient table is moved to center different anatomic locations in the center of the magnet when performing aortic runoff evaluations or when the need for imaging the thoracic and abdominal aorta arises.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.